Compensating Non-Ideal Entangled-Photon State Generation

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Entangled-photon pairs are a key resource for many quantum applications including quantum networking and communications. However, entanglement is a fragile property that is easily degraded or destroyed by distinguishability, loss or non-ideal generation. Generation can be modelled by

$$|\Psi\rangle = \sqrt{\varepsilon}|HV\rangle + e^{i\phi}\sqrt{1-\varepsilon}|VH\rangle, \tag{1}$$

where ε is the amplitude mismatch factor, ϕ, is the relative phase, and $|H\rangle$ and $|V\rangle$ are the horizontal and vertical polarizations, respectively. Adjusting pump polarization or crystal tilting may be used to control ϕ [1], but in some applications, such as domain-engineered, dual-process spontaneous parametric downconversion (SPDC) [2], there are no convenient ways to change ϕ, which is fixed during crystal fabrication. Here, we present a technique to compensate for effects of the relative phase, ϕ, using quarter-wave plates placed after the SPDC crystal.

Fig. 1 plots the calculated polarization-entanglement fringes for $|\Psi\rangle$ in Eq. 1 with $\varepsilon = 0.5$ and $\phi = \pi/4$. These fringes are measured by first separating the SPDC into signal and idler arms, then setting the signal polarization to $|H\rangle$, $|V\rangle$, $|D\rangle$ or $|A\rangle$ (corresponding to signal half-wave plate (HWP) angles of 0°, 45°, 22.5°, or -22.5°) and measuring the coincidences as a function of idler HWP angle. As generated (without any compensation measures), the average visibility of the polarization fringes is reduced (see Fig. 1a; visibility is defined as (maximum – minimum)/(maximum + minimum)). We can compensate the effects of ϕ by placing quarter-wave plates (QWPs) in each of the SPDC arms and rotating them by 45°. Fig 1b shows the calculated polarization fringes after applying the 45° QWP rotations. The visibilities of polarization-entanglement fringes are all equal to 1 with an offset in idler HWP angle proportional to ϕ.

We can see the effect of the compensation from the QWPs by calculating the Clauser-Horne-Shimony-Holt (CHSH) S parameters [3]. For the as-generated state with $\phi = \pi/4$ (Fig. 1a), the best S parameter value is 2.450. After applying the compensation (Fig. 1b), an S parameter value of 2.8284 can be achieved, which is equal to the maximum allowed value ($S = 2\sqrt{2}$).

The action of the 45°-oriented QWPs converts light in both arms into circular polarizations. Measurement of the signal in a particular linear polarization projects the idler into a corresponding linear (or nearly linear) polarization state. In our numerical studies that included both non-zero ϕ and $\varepsilon \neq 0.5$, we observed that the average visibility and S value after QWP compensation depended only on ε.

Such compensation will be useful in deployed SPDC-based sources because high-quality entanglement can be easily produced from non-ideally generated states.

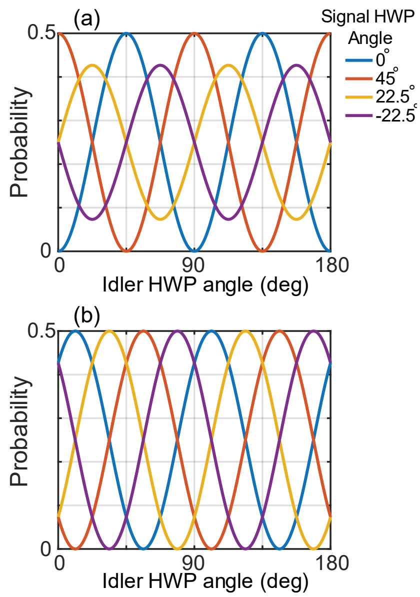

Fig. 1: *Calculated polarization-entanglement fringes (a) as generated and (b) after QWP compensation.*

References

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